Space Radiation 101

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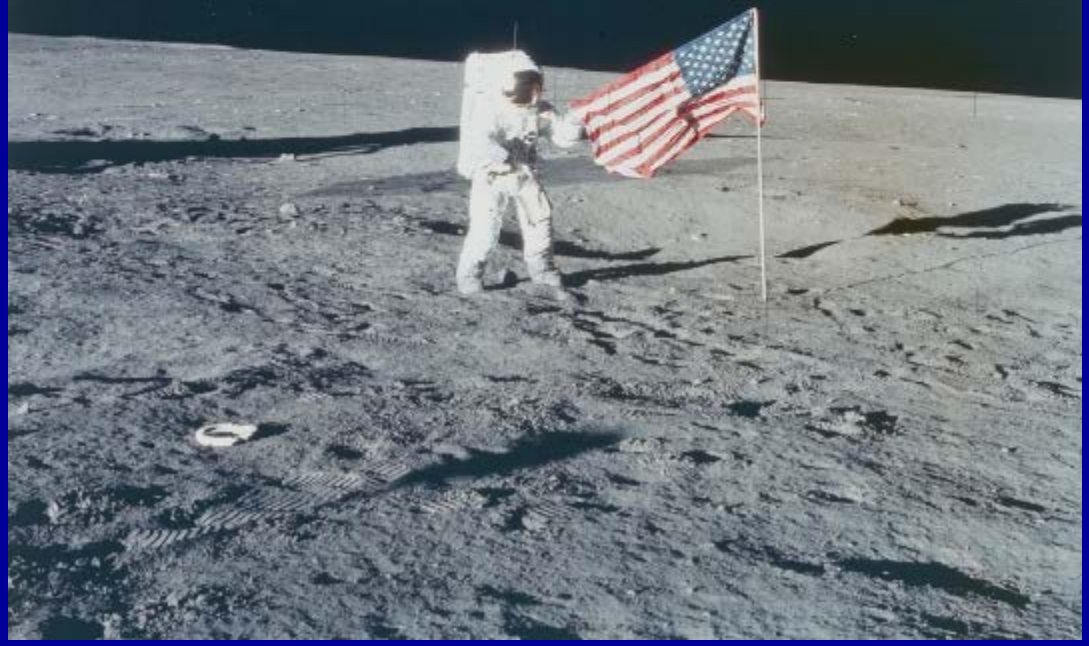
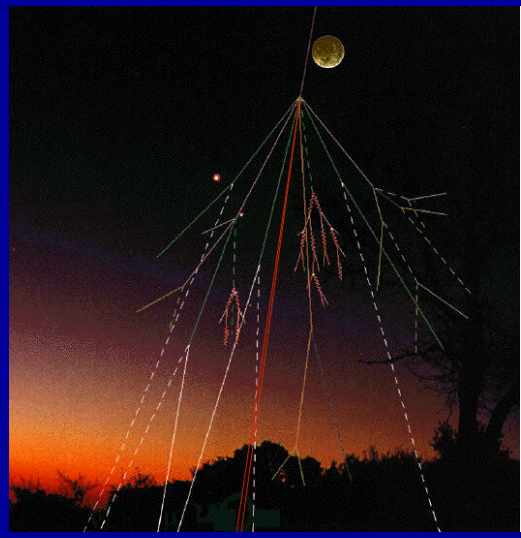
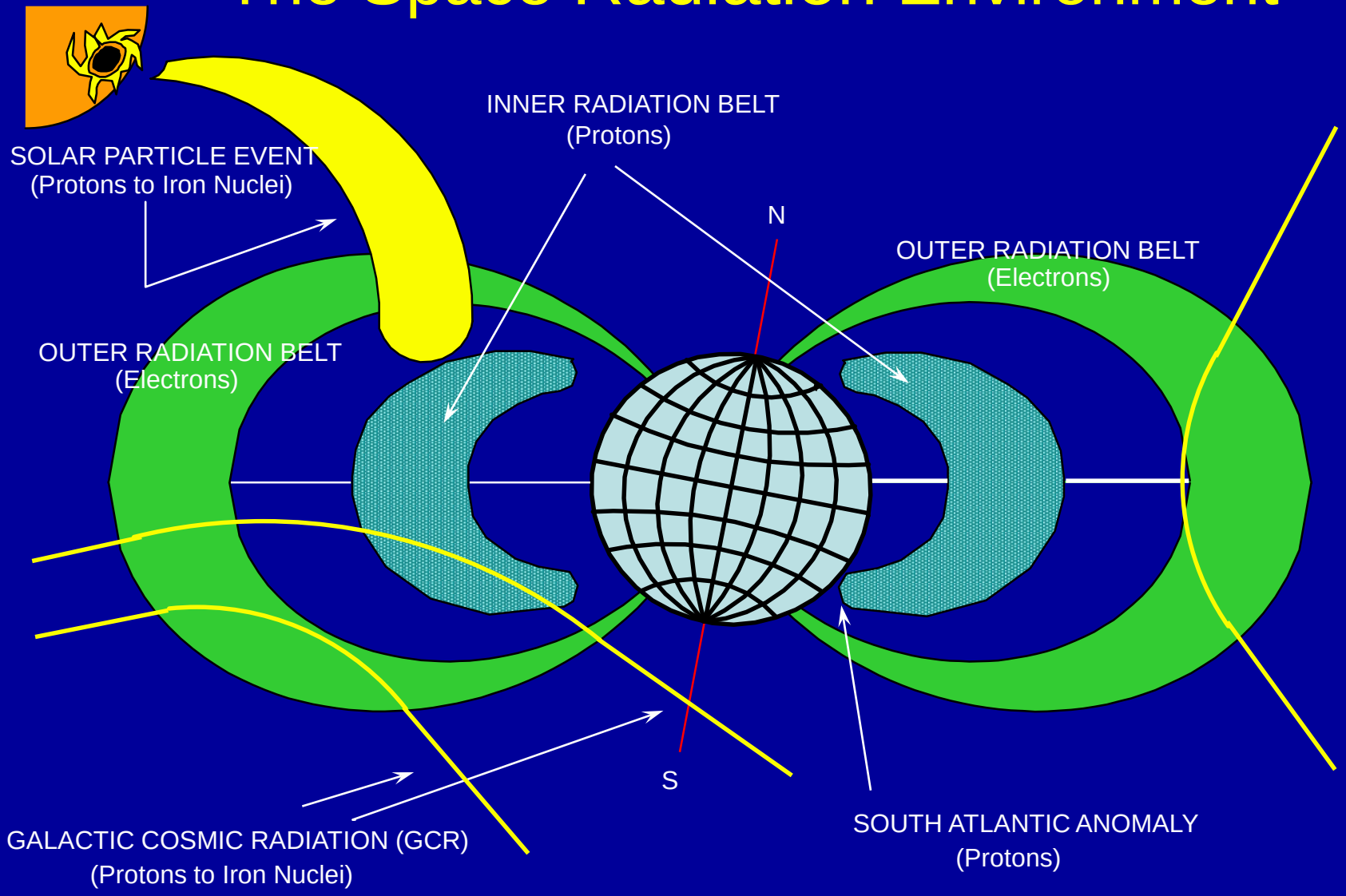


Outline

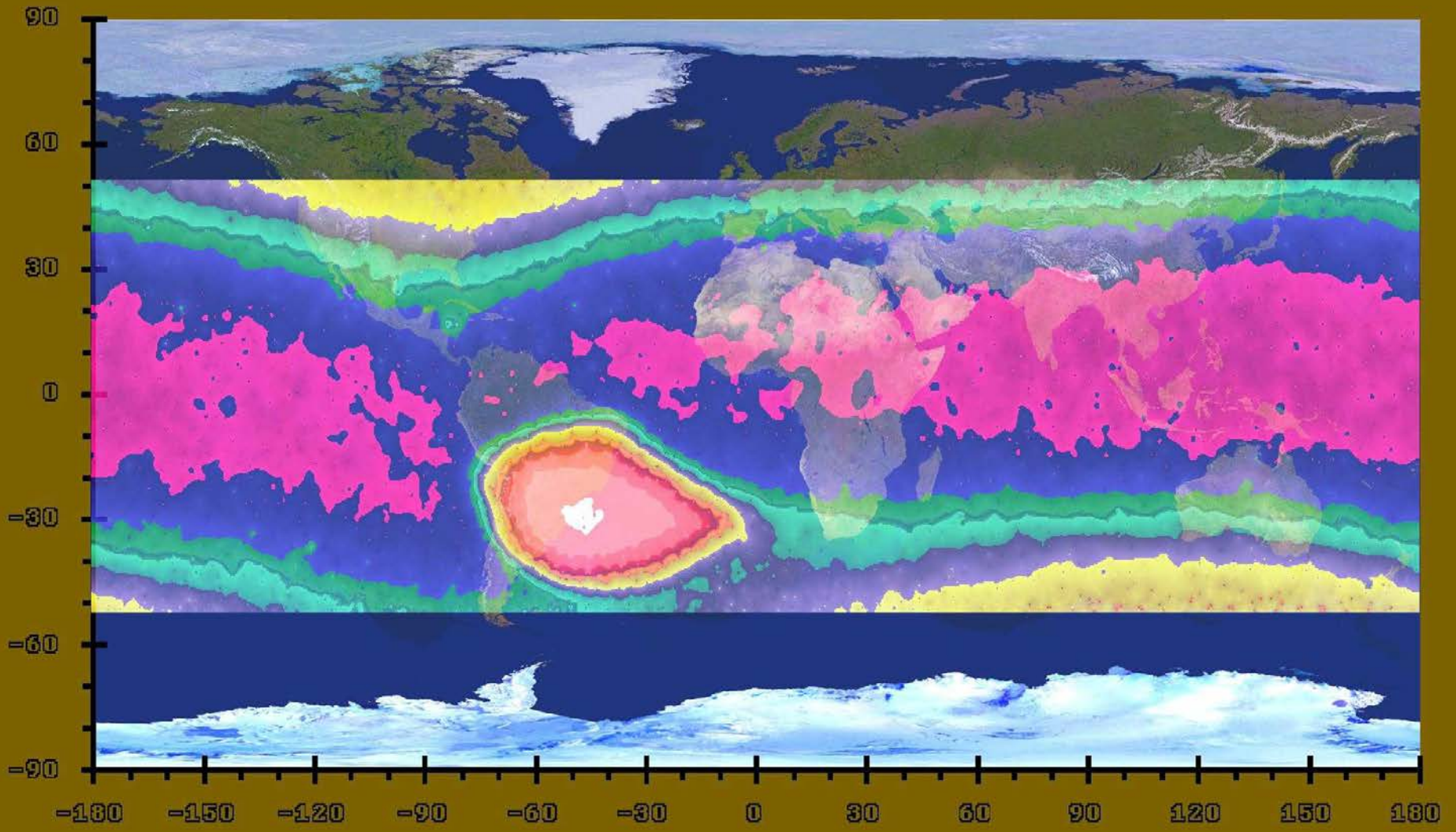
- Space radiation environment
- Major space radiation health risks
- Evident biological effects of space radiation in astronauts



The Space Radiation Environment



Representation of the major sources of ionizing radiation of importance to manned missions in low-Earth orbit. Note the spatial distribution of the trapped radiation belts.

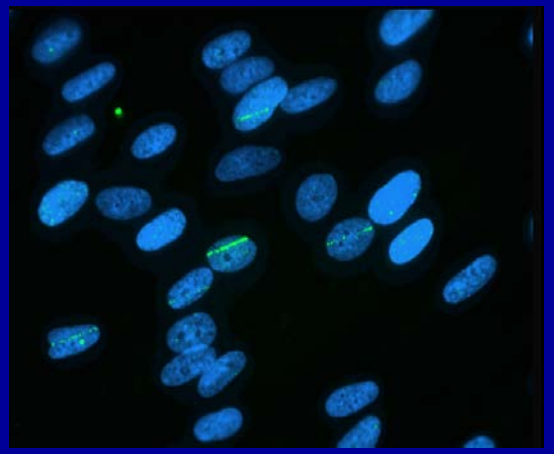


Inclination = 51.6 deg.
Altitude ~ 385 km.
November 2, 1997 -
November 4, 1997

NASA-MIR 6 - Radiation Dosage
TEPC- PRIRODA

0 nGy/min 6500

Summary of the space radiation environment



- Major sources: Trapped protons, GCR, solar particle events
- Radiation type: Protons and heavy ions (high-LET)
- Energy of interest: 100 MeV/u ~10000 MeV/nucleon
- Secondary neutrons
- Small amount of X-rays and gamma rays
- Ultraviolet radiation
- The dose rate is low except for SPE; Only a small fraction of the cells are traversed by particles at a given time.

Radiation Units

Absorbed dose: Gy — 1 Gy = 100 cGy = 1000 mGy

Dose equivalent: Sv — 1 Sv = 100 cSv = 1000 mSv

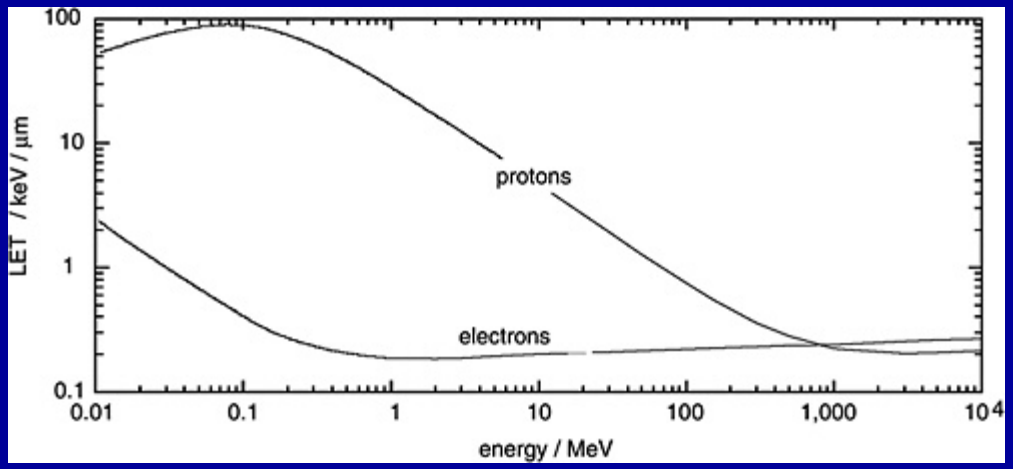
Equivalent dose: Gy-Eq

$$1\ Sv = 1\ Gy \times Q$$

LET: Linear energy transfer

Low LET: X-rays, gamma rays, high energy light ions

High LET: Heavy ions



Dose and dose rate from space radiation exposure are low (with exception of Solar Particle Events)

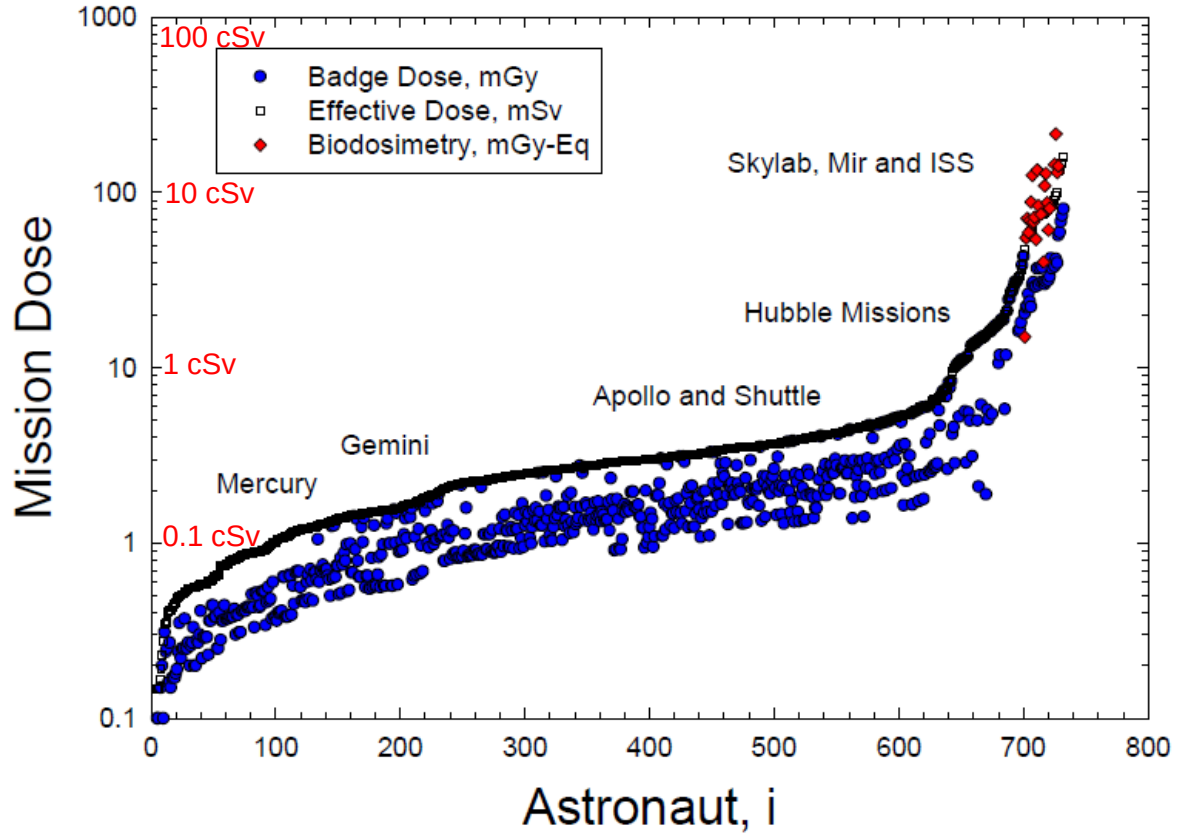


Figure 4-7. ***Summary of mission personnel dosimetry from all past NASA crews (Cucinotta et al., 2008). Effective dose and population average biological dose-equivalent for astronauts on all NASA space missions, including Mercury, Gemini, Apollo, Skylab, Apollo-Soyuz, space shuttle, shuttle-Mir, and ISS missions.***

Mission	Altitude (nm)	Inc. (deg)	Duration (days)	Dose (cSv)
STS-94	160	28.5	15.7	0.27
STS-95	310	28.5	8.9	2.1

From HRP Evidence Book

Space radiation monitoring

Physical dosimeters
- Absorbed dose
- Dose equivalent (LET)
- Charged particle type and energy
- Neutrons

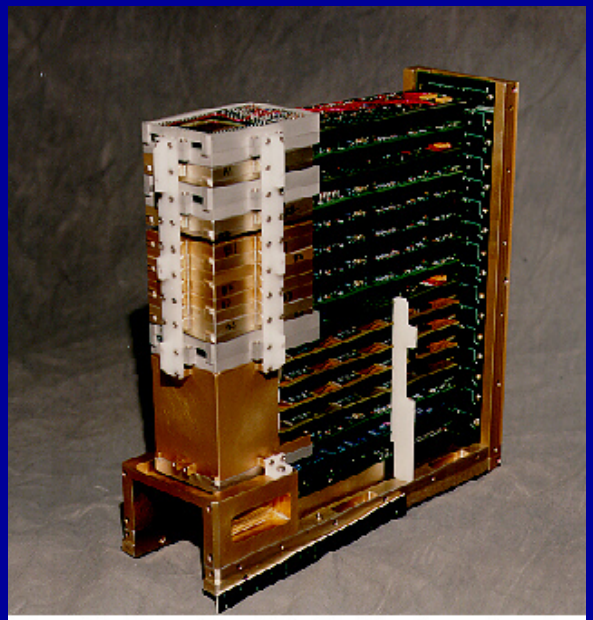


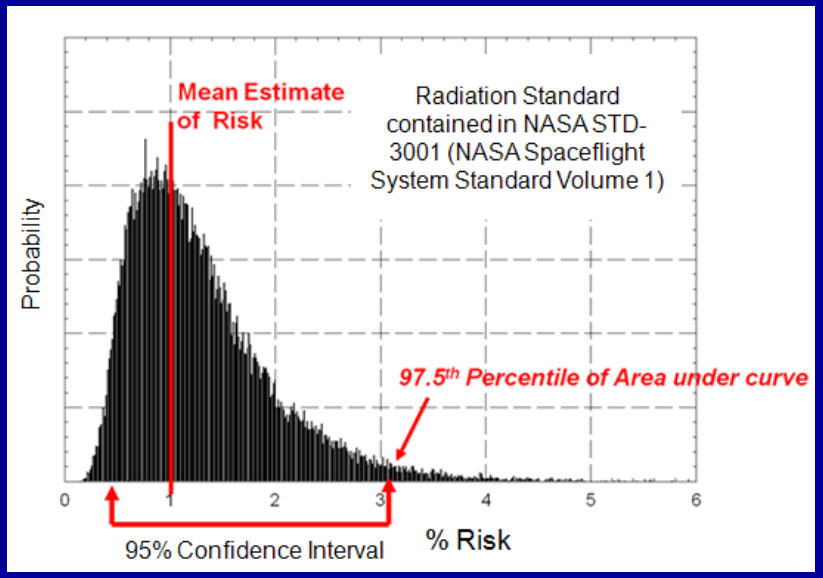
Figure 14. Charged particle directional spectrometer (CPDS).

Figure 13. Tissue equivalent proportional counter (TEPC).

Exposure Limits for Spaceflight

Organ Specific Exposure Limits for Astronauts (cSv)			
Exposure Interval	**Blood Forming Organs**	**Eye**	**Skin**
30 Days	25	100	150
Annual	50	200	300
Career	150 - 400 [200 + 7.5(age - 30) for men] 100 - 300 [200 + 7.5(age - 38) for women]	400	600

Cancer PEL is determined based on 3% excess cancer mortality risks. Administrative PEL is lower when uncertainties are considered.



From NASA STD-3001 (NASA Spaceflight Systems Standard V. 1

Space Radiation Risks

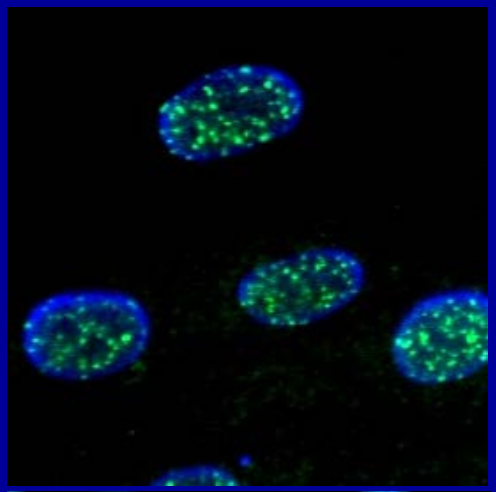
- Risk of Radiation Carcinogenesis
- Risk of Acute (In-flight) and Late Central Nervous System (CNS) Effects from Radiation Exposure
- Risk of Cardiovascular Disease and Other Degenerative Tissue Effects from Radiation Exposure and Secondary Spaceflight Stressors
- Risk of Acute Radiation Syndromes Due to Solar Particle Events (SPEs)

Risks due to space radiation exposure can be different from those due to exposures to gamma or X-rays

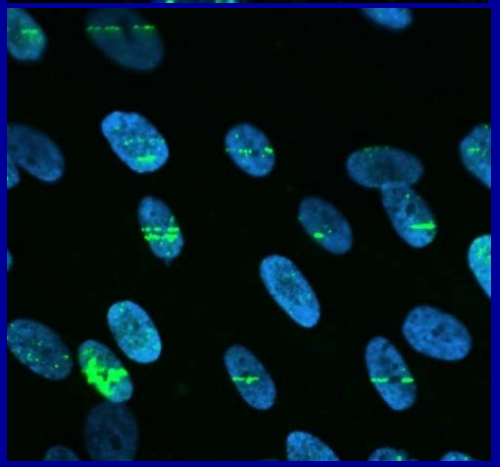
DSB induction

(Desai et al. Rad Res 2005)

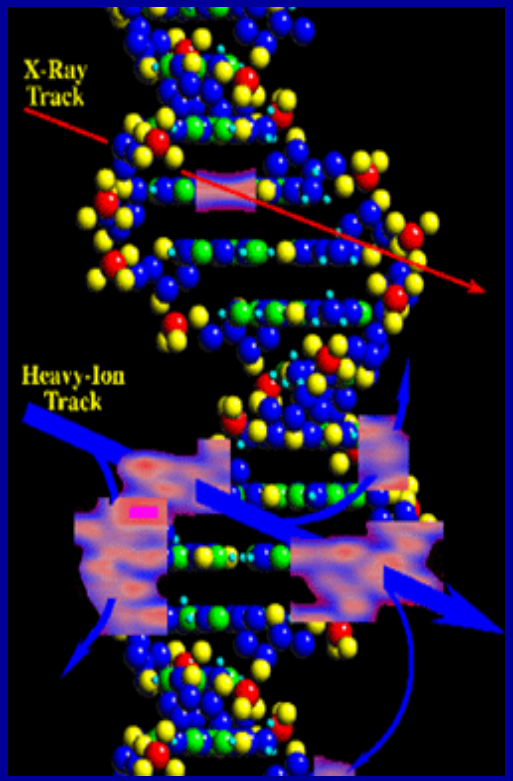
Low-LET
X-rays
Gamma rays



High-LET
Space radiation



Severity of DSB



DNA damage induced by high-LET radiation are more difficult to repair

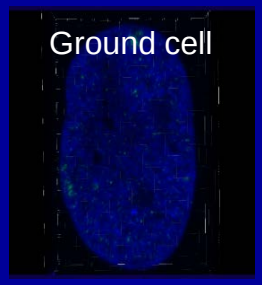
Contents lists available at ScienceDirect

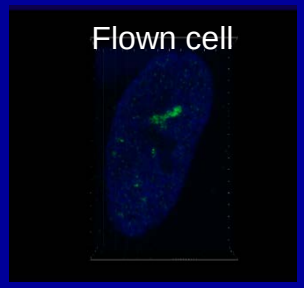
Life Sciences in Space Research

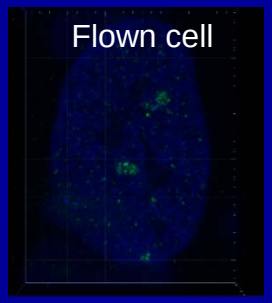
journal homepage: www.elsevier.com/locate/lssr

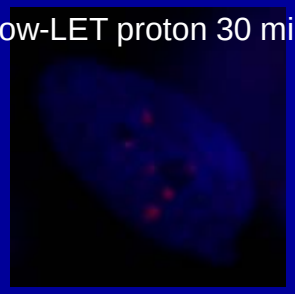
Detection of DNA damage by space radiation in human fibroblasts flown on the International Space Station

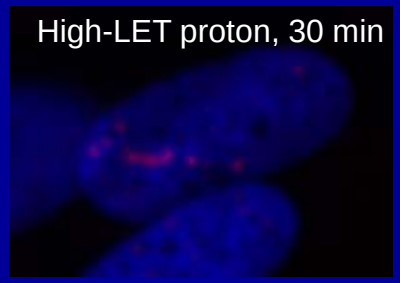
Tao Lu[a,b], Ye Zhang[c], Michael Wong[a], Alan Feiveson[a], Ramona Gaza[a,d], Nicholas Stoffle[a,d], Huichen Wang[e], Bobby Wilson[f], Larry Rohde[b], Louis Stodieck[g], Fathi Karouia[h,i], Honglu Wu[a,*]

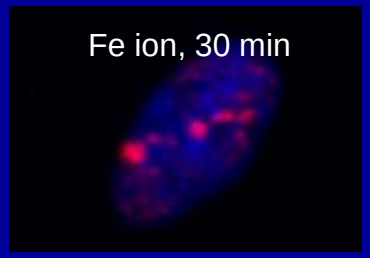


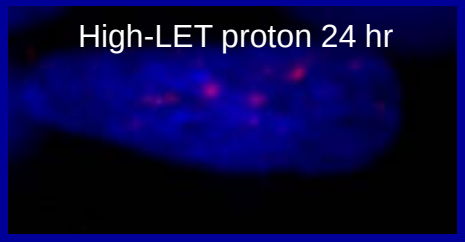


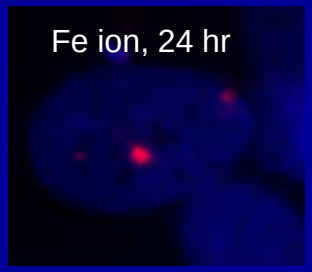












DNA double strand breaks (DSB) were detected using the γ-H2AX assay (Phosphorylation of a histone protein).

Large foci found in flight samples were most likely induced by high-LET protons or high-LET heavy ions.

What are the evident biological effects of space radiation in astronauts?

- Light flash/cataract
- Chromosome aberrations in PBMC
- Cancer/CVD???

Light Flashes

- Light flashes were first reported by Apollo astronauts.
- The effects were later verified with ground studies.

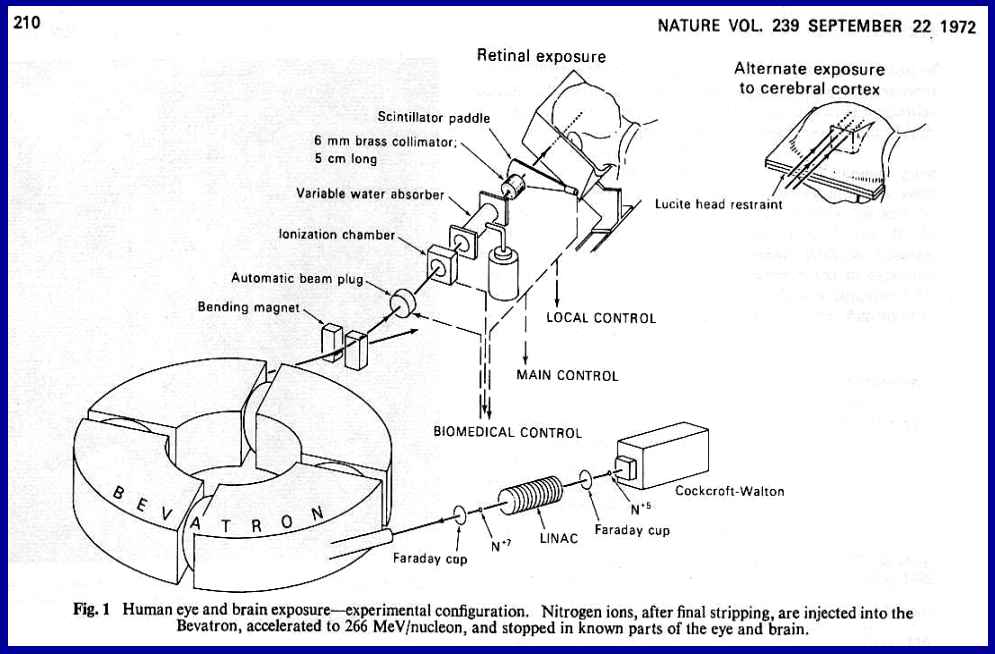
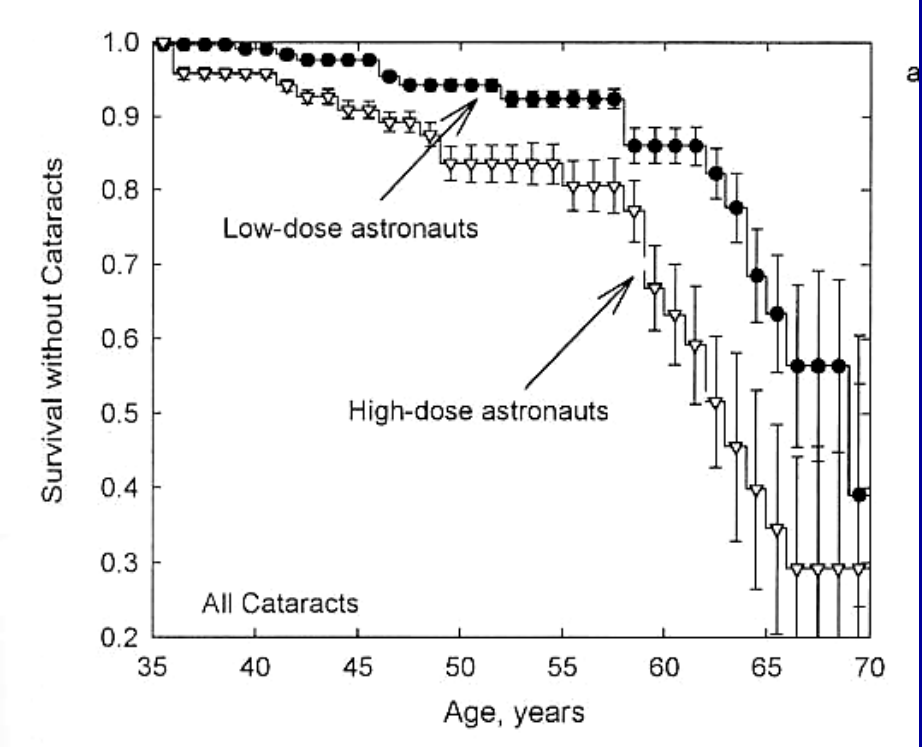


Fig. 1 Human eye and brain exposure—experimental configuration. Nitrogen ions, after final stripping, are injected into the Bevatron, accelerated to 266 MeV/nucleon, and stopped in known parts of the eye and brain.

(Pinsky et al. Science 1974)

Cataracts

Cucinotta et al. 2001



Brenner et al. Rad. Res. 1993

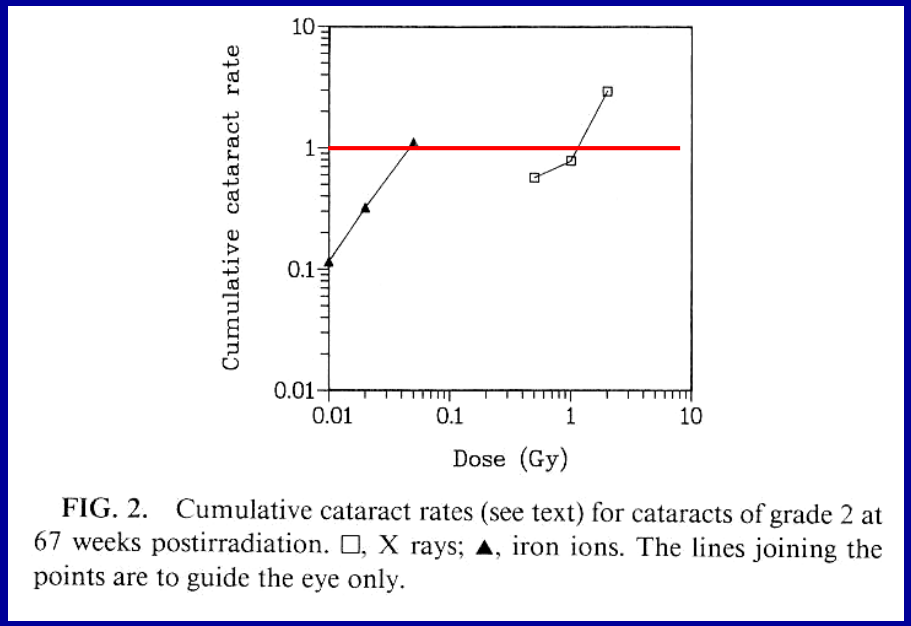
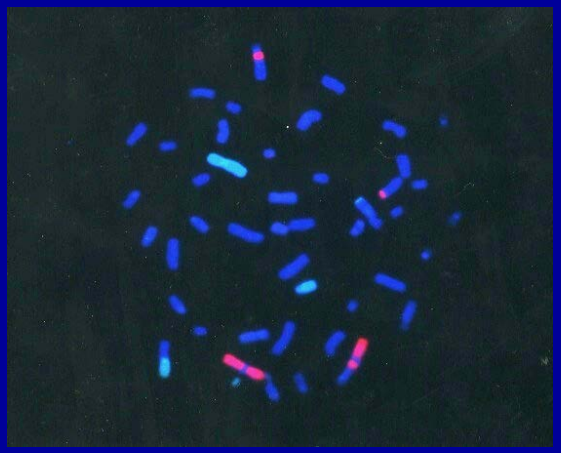


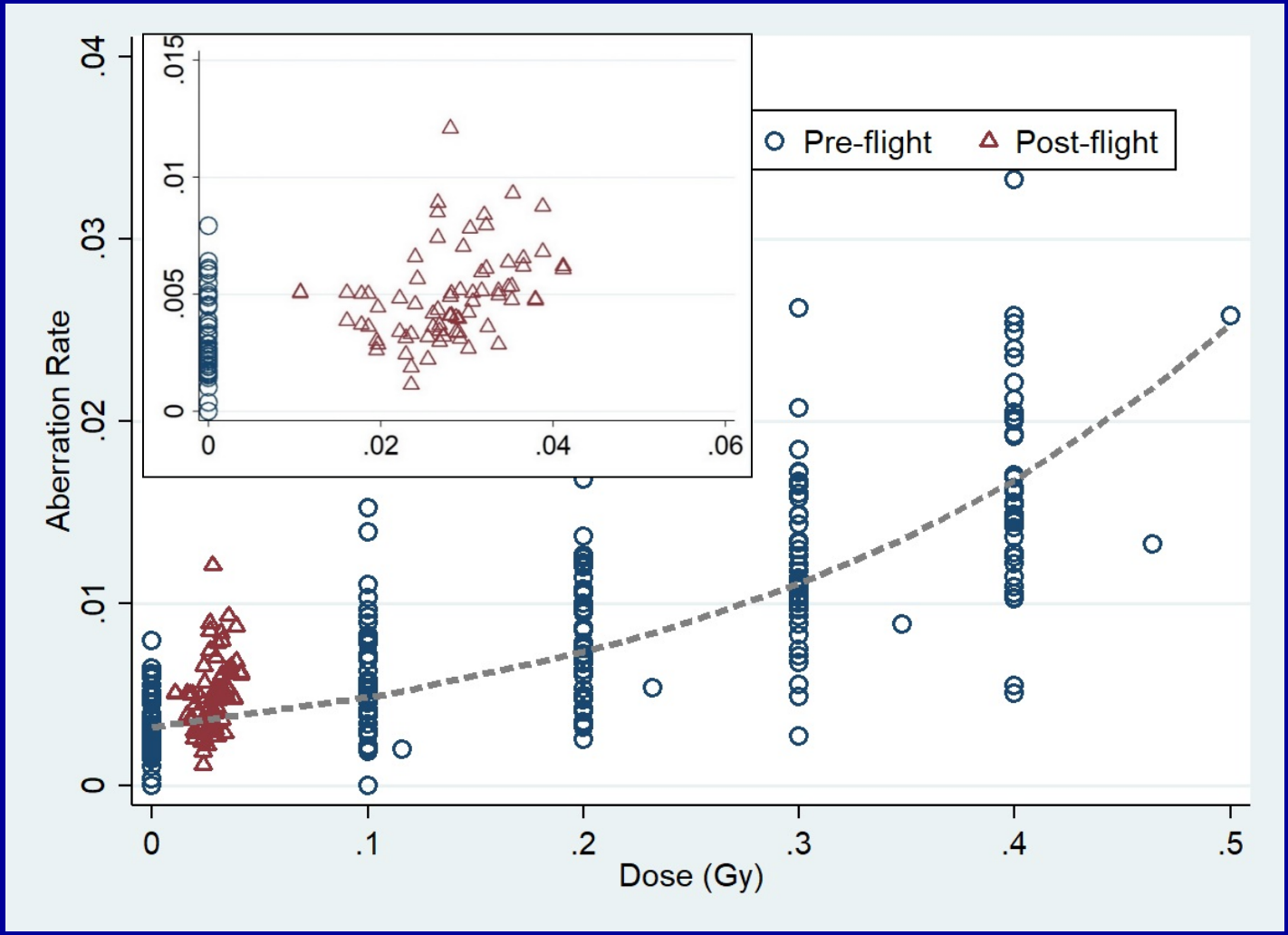
FIG. 2. Cumulative cataract rates (see text) for cataracts of grade 2 at 67 weeks postirradiation. □, X rays; ▲, iron ions. The lines joining the points are to guide the eye only.

- Early onset of cataract was seen in astronauts who received higher doses of radiation in the eye.
- Animal studies have shown a high effectiveness of high-LET radiation in causing cataract.

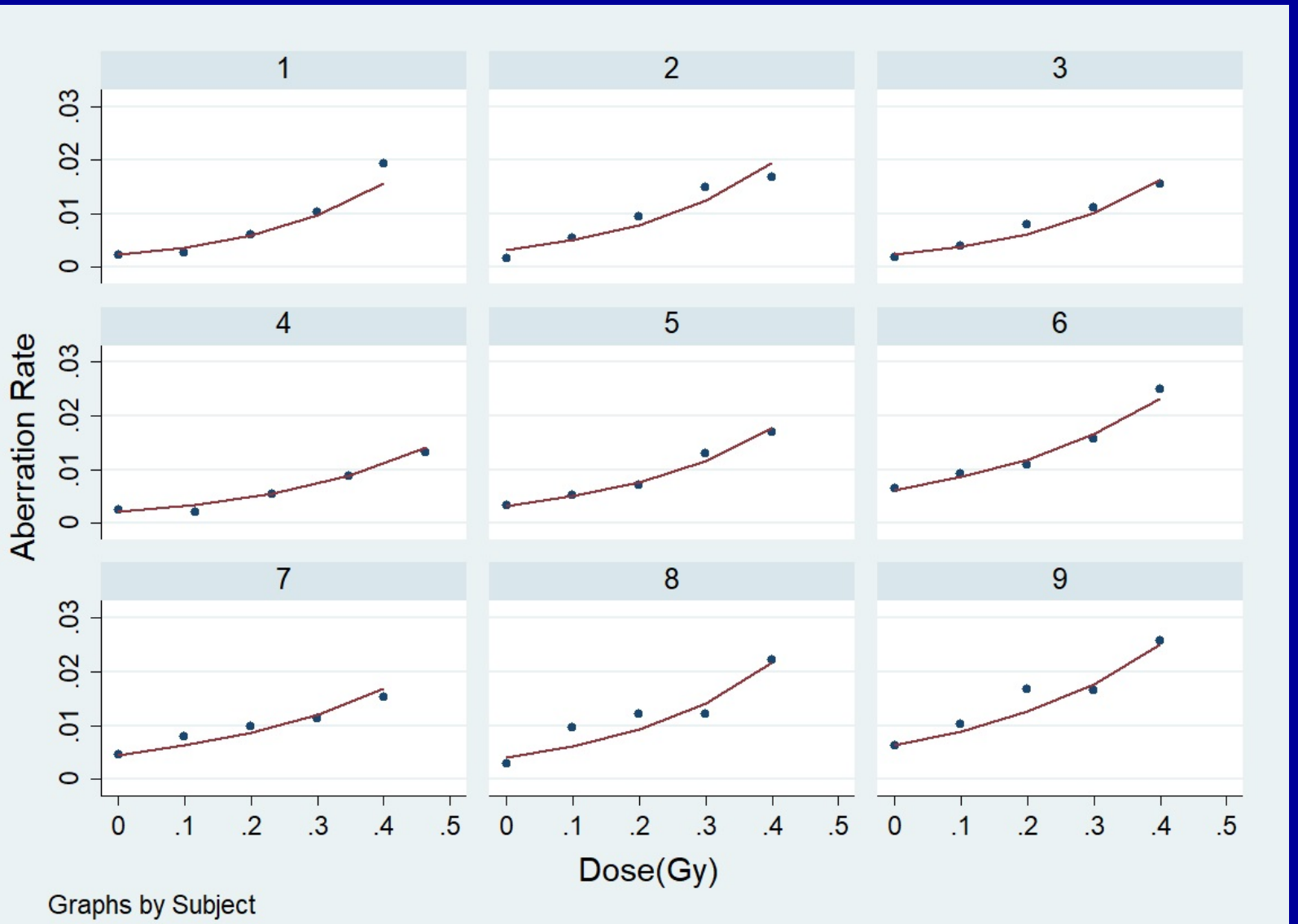
Chromosome aberrations observed in astronauts' PBMC

- Pre-flight blood samples were analyzed for 43 crewmembers; pre-flight samples were collected at ~2 weeks before launch
- Pre-flight samples were exposed ex vivo to gamma rays acutely at a set of doses from 0 to 2 Gy
- Post-flight blood samples were analyzed for 39 crewmembers
- 1st post-flight samples were collected between 2 and 4 weeks after landing; 2nd post-flight samples were collected at >6 mo. after landing
- 5 of the 39 crewmembers flew twice on the ISS
- Chromosome aberrations were analyzed using FISH with 3 chromosomes stained in 3 different colors
- Chromosome aberrations were also compared to cytokines measured before, in and after mission for 22 of the 39 crewmembers

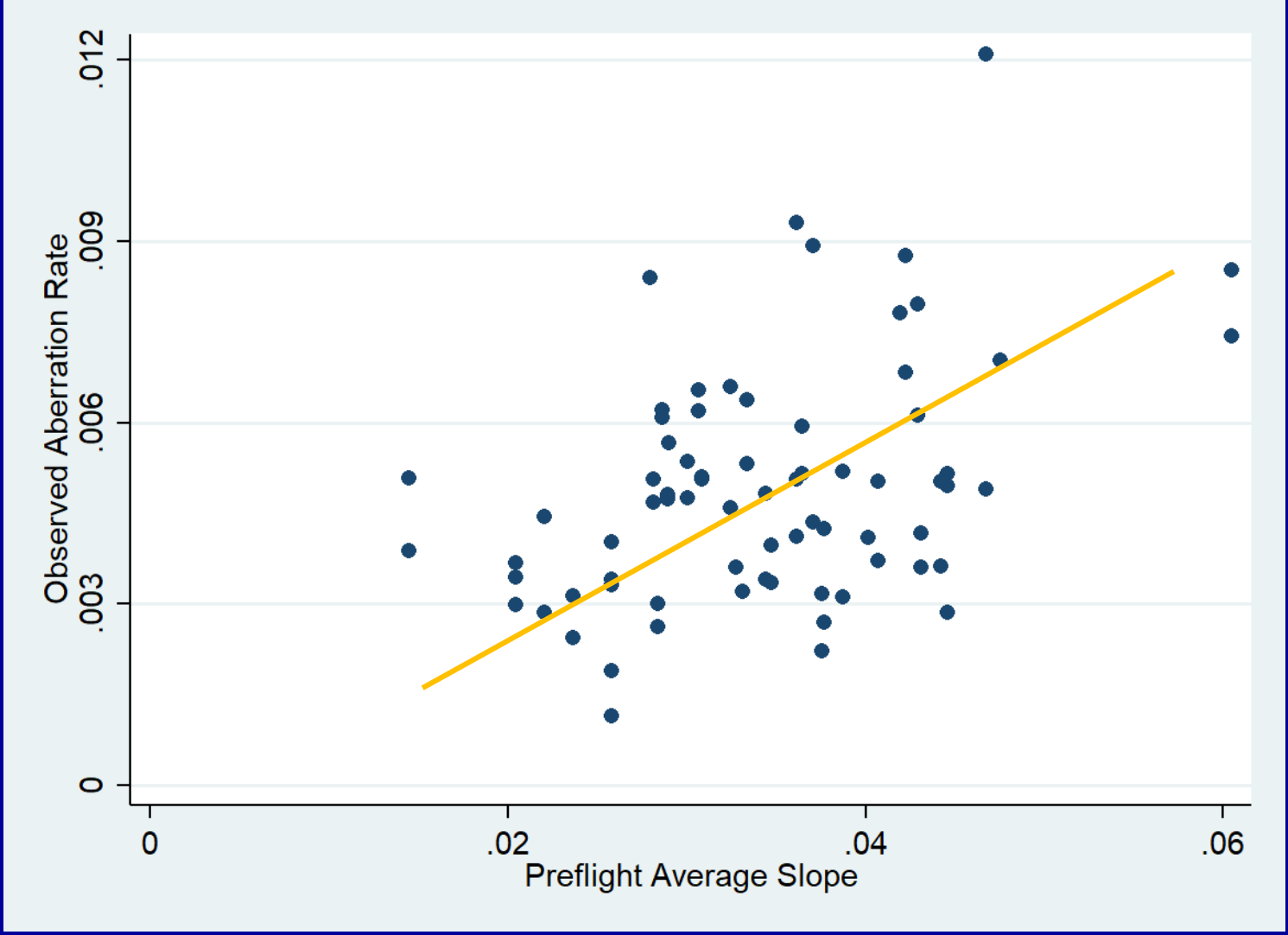




Chromosome aberration rate (AR) in lymphocytes, collected pre-flight from the ISS crewmembers, after exposure to gamma rays ex vivo (blue circles) as a function of dose. Red triangles represent the post-flight AR as a function of the estimated BFO dose for the individuals. The average BFO dose received during ISS missions was 0.028 Gy, and the average AR post-mission was 0.0049, resulting in an average RBE of 3.2. (Feiveson et al. unpublished)



Poisson regression of pre-flight dose response for individual crewmembers. (Feiveson et al. unpublished)



Post-flight AR as a function of the average preflight dose response for individual ISS crewmembers, indicating that radiosensitivity determined preflight is a predictor for post-flight AR. (Feiveson et al. unpublished)

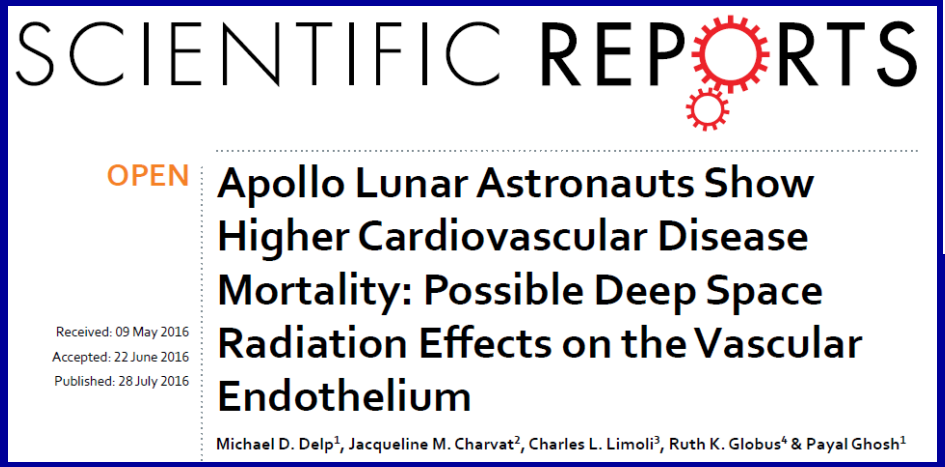
Cancer/CVD death caused by space radiation?

Primary Cause of Death among NASA Astronauts as of 12/31/2019			
	Flyer	**Non-Flyer**	**Total**
Cancer	**19**	**2**	**21**
AML	1		1
Breast	1		1
Colon	1		1
Gallbladder	1		1
Glioblastoma		1	1
Lung Cancer	1		1
Lymphoma of the Brain	1		1
Melanoma	3		3
Mesothelioma	1		1
Myelodysplastic Syndrome	1		1
Nasopharyngeal	1		1
Pancreas	2		2
Prostate	5		5
Unknown Cancer (Presumed GI)		1	1
CVD/Stroke	**10**	**3**	**13**
Accident	**6**	**3**	**9**
Occupational Accident	**12**	**6**	**18**
Illness/Other	**7**	**1**	**8**
Unknown	**1**		**1**
Grand Total	**56**	**14**	**70**

- Lung cancer death rate is significantly lower than the general population.
- Percentage of cancer death is high, but is this due to the healthy worker effect alone?

Data from Mary Wear

Published studies on cancer and CVD death in astronauts



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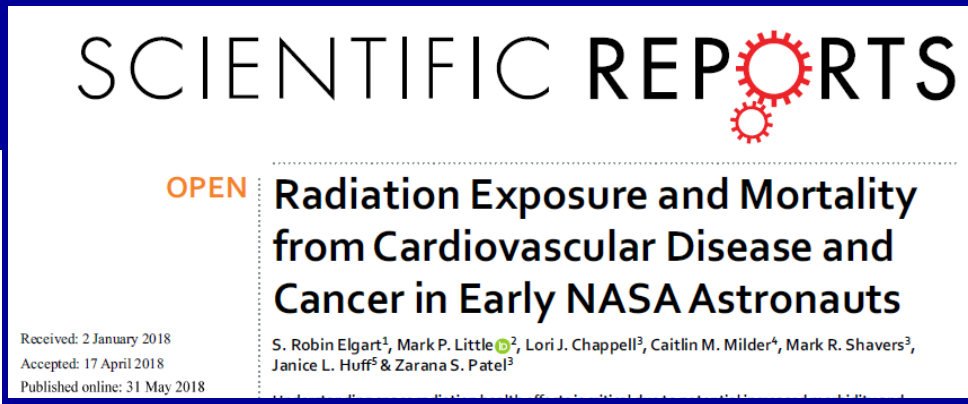
Apollo Lunar Astronauts Show Higher Cardiovascular Disease Mortality: Possible Deep Space Radiation Effects on the Vascular Endothelium

Received: 09 May 2016
Accepted: 22 June 2016
Published: 28 July 2016

Michael D. Delp[1], Jacqueline M. Charvat[2], Charles L. Limoli[3], Ruth K. Globus[4] & Payal Ghosh[1]



SCIENTIFIC REPORTS

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Radiation Exposure and Mortality from Cardiovascular Disease and Cancer in Early NASA Astronauts

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S. Robin Elgart[1], Mark P. Little[2], Lori J. Chappell[3], Caitlin M. Milder[4], Mark R. Shavers[3], Janice L. Huff[5] & Zarana S. Patel[3]

SCIENTIFIC REPORTS

OPEN

Contrapositive logic suggests space radiation not having a strong impact on mortality of US astronauts and Soviet and Russian cosmonauts

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Robert J. Reynolds[1], Igor V. Bukhtiyarov[2], Galina I. Tikhonova[2], Steven M. Day[1], Igor B. Ushakov[3] & Tatyana Y. U. Gorchakova[2]

- Conclusions in some of the studies have been disputed.
- NASA is currently conducting statistical analysis of the cancer and CVD data for the astronauts.

Summary

- Space radiation is a major health concern for long-duration missions.
- Effects of space radiation exposure have been observed in astronauts.